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SHEAR-LAG TESTS OF TWO BOX BEAMS WITH

CORRUGATED COVERS LOADED TO FAILURE

By Patrick T. Chiarito

Langley Memorial Aeronautical Laboratory
Langley Field, Va.

NACA

WASHINGTON

NATIONAL ADVISORY COMMITTEE FOR AERONAUTICS

ADVANCE RESTRICTED REPORT

SHEAR-LAG TESTS OF TWO BOX BEAMS WITH

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SUMMARY

Strain measurements were made on the compression side of two box beams with corrugated aluminum-alloy covers loaded to failure. Angles formed from sheet were used for corner flanges in beam 1; whereas extruded angles were used in beam 2. By use of the shear-lag theory the stresses in the corner flanges at the root could be predicted to approximately 10 percent for beam 1 and 5 percent for beam 2. Failure in each beam occurred in the corner angle at a stress that was above the compressive yield stress for the material.

INTRODUCTION

Little experimental evidence has been published heretofore concerning the reliability of the shear-lag theory at high stresses. Reference 1 reported the results of tests made at the Langley Memorial Aeronautical Laboratory of box beams with flat cover sheets and Z-stiffeners loaded to destruction. Tests have recently been made of box beams with corrugated covers; the experimental results of these tests are presented herein and are compared with theoretical results obtained by the shear-lag theory of reference 2.

BENDING TESTS OF THE BOX BEAMS

Test specimens.- Two box beams with constant cross sections and corrugated covers were used for the tests. Details of the cross sections of beams 1 and 2 are given in figure 1. The bulkheads were of steel; whereas, the other parts of the beams were of aluminum alloys. All rivets were of A17S-T alloy. The compression cover for

each beam was made from 0.051-inch 24S-RT alloy corrugated sheet with a nominal pitch of $2\frac{1}{2}$ inches and, with the exception of the root bulkhead of beam 2 where $\frac{5}{32}$-inch rivets were used, was attached to all bulkheads by $\frac{1}{8}$-inch rivets. The two beams were distinguished by the difference in their corner-flange angles: for beam 1, $\frac{3}{4}$- by $\frac{3}{4}$-inch angles formed from 0.064-inch 24S-T alloy sheet were used; whereas for beam 2, $\frac{3}{4}$- by $\frac{3}{4}$- by $\frac{3}{16}$-inch angles of 24S-T alloy extrusions were used.

Properties of materials.- The stress-strain curve shown in figure 2(a) was obtained as a result of a compression test of a cycle-welded pack of the corrugated sheet approximately $1\frac{5}{8}$ inches long. Four samples about 3 inches long of the extruded corner-flange angle used in beam 2 were tested as angle columns for obtaining the curve of figure 2(b).

Loading apparatus.- In order to obtain a condition of distributed loading, a double whippletree was used to anchor the beam to the floor by means of four straps spaced at 22 inches along each web of the half span. The load was applied through a yoke at the center of the full span by a portable hydraulic jack of 100 kips capacity.

Test procedure.- Strain measurements were taken at corresponding stations in the four quadrants of the cover of the full span. As shown in figure 3, strains were measured on both sides of the cover sheet at the crests and valleys of the corrugations. Preliminary tests indicated that measurements in the four quadrants were approximately equal. Additional gages were then mounted at intermediate gage positions on both sides of the sheet in one quadrant in order to provide a more complete chordwise distribution of measured strains. Strain gages were located at the root and at stations $1\frac{1}{4}$ and $2\frac{1}{2}$ inches from the root.

All strain measurements were made with SR-4 electrical strain gages. Approximately 100 strain gages were used on each beam. A gage length of 1 inch was used except for measurements between corner-flange rivets on beam 1, where a $\frac{1}{2}$-inch gage length was used.

Strains were measured at a minimum of three loads in the elastic range in an attempt to verify the linear variation of strain with respect to applied load. At loads which produced stresses above the proportional limit in the regions of highest stress, strain measurements were taken after each application of a small load increment (about 5 percent of the ultimate load) in order to obtain a more precise relationship between load and stress. Strains were measured up to a jack load of 13.0 kips (92 percent of the ultimate load) for beam 1 and 19.0 kips (86 percent of the ultimate load) for beam 2.

In order to reduce thermal errors in the measurements, the temperature in the vicinity of the box beams was controlled to ±1°F.

Accuracy of measurements.- The total applied jack load was accurate to approximately 0.5 percent. The thicknesses of all parts made from aluminum-alloy sheet were obtained by micrometer measurements with an accuracy of 0.0002 inch. The areas of the tension flange angles as given by a structural aluminum handbook were considered to be satisfactory. Strain measurements were made with an accuracy of 0.00002 for strains up to 0.001; for larger strains, the error was probably not more than 2 percent.

SYMBOLS

A cross-sectional area, square inches

A_F cross-sectional area of idealized corner flange, square inches

A_L cross-sectional area of cover sheet for half-beam, square inches

A_T sum of A_F and A_L, square inches

t thickness of cover sheet, inch

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h effective depth of beam, inches

σ_L chordwise average of longitudinal stresses in cover sheet, kips per square inch

σ_F longitudinal stress in corner flange, kips per square inch

P load applied at each loading strap, kips

Mz/I longitudinal stress as defined by the engineering theory of bending, kips per square inch

M bending moment, kips-inches

I geometric moment of inertia about centroidal axis, inches^4

z distance from centroidal axis to a given fiber, inches

TEST RESULTS AND COMPARISONS WITH CALCULATIONS

Strain-Gage Tests

  The measured strains were converted to stresses by using the stress-strain curve shown in figure 2(a) and neglecting the effect of any possible transverse stresses. The stresses on opposite sides of the cover sheet were then averaged at each gage position, and these average values were used in the comparisons of the test results with the calculated results. The calculations were made in accordance with the substitute single-stringer method as given in reference 2. The following table gives the basic data used in the analysis of each beam:

Beam	A_F (sq in.)	A_L (sq in.)	A_T (sq in.)	t (in.)	h (in.)	$\dfrac{A_F}{A_L}$
1	0.181	1.035	1.216	0.0531	6.06	0.175
2	.344	1.035	1.379	.0531	6.03	.332

Beam 1.- The chordwise distributions of stresses at
several stations near the root of beam 1 are shown in
figure 4 for a jack load of 11.0 kips (78 percent of the
ultimate load) or 688 pounds at each loading strap. These
distributions were typical of the elastic range. The cubic
equation given in reference 3 was used to calculate the
chordwise stress distribution for the centroidal plane of
the corrugated cover; this stress distribution was then
corrected for the geometry of the corrugations.

The experimental corner-flange stresses for beam 1
are shown in figure 4 to be about 10 percent lower than
the calculated stresses. The differences between stresses
on the crests and in the valleys suggest secondary bending
in the corrugated cover at station $2\frac{1}{2}$ inches from the root
(fig. 4(c)).

Beam 2.- Figure 5 shows the chordwise distribution of
stresses at several stations near the root of beam 2 for a
jack load of 16.0 kips (72 percent of the ultimate load),
or 1.0 kip at each loading strap. Variation of stress with
load for most of the gages was found to be linear up to a
jack load of 16.0 kips.

In figure 5, the average of the experimental corner-
flange stresses for beam 2 is found to be approximately
5 percent higher than the calculated stresses. As was the
case for beam 1, secondary bending in the cover was
suggested by the differences between stresses on the crests
and in the valleys.

Measurements at high loads.- Curves of applied load
plotted against stress, for individual measurements, showed
that the stresses were not always proportional to the loads
in the higher range. For beam 1, 52 percent of the gages
showed linear variation of stress with load up to the maxi-
mum measured stress. For 46 percent of the gages, there
was a break in the straight line at a load of about 12.0
kips (85 percent of the ultimate load). The corresponding
stresses were between 10.0 and 35.0 kips per square inch.
At present, no satisfactory explanation can be made for the
breaks in the load-stress curves. The remaining 2 percent
of the gages were discarded.

Because many gages showed linear variation of stress
with load up to the maximum measured stress and because
the gages in the regions of high stresses showed no

definite indications to the contrary, it may be concluded that the shear-lag effect for beam 1 was not appreciably altered by local yielding.

For beam 2, 76 percent of the gages showed stresses that varied approximately linearly with load up to the maximum measured stress. For 18 percent of the gages, a break in the straight line occurred at 13.0 kips (59 percent of the ultimate load); whereas for 6 percent of the gages, a break occurred at 17.0 kips (77 percent of the ultimate load). Stresses corresponding to the loads at which these breaks occurred were between 12.0 and 30.0 kips per square inch. The breaks had no apparent relation to the applied loads or to the yield stress.

When the data for beam 2 are considered as a whole, they appear to support the tentative conclusion, drawn from the test on beam 1, that the shear-lag effect was not appreciably changed at high stresses.

Ultimate-Strength Tests

Failure of beams.- The failure in beam 1 occurred at a jack load of 14.1 kips. Figure 6 shows the distortion of the corner flange and its immediate vicinity. The applied load was released soon after this local failure in order to prevent extensive damage to the remainder of the beam. There was no other apparent damage, except that several cover-to-bulkhead rivets failed.

Beam 2 failed at a jack load of 22.1 kips by buckling and twisting of the corner flange near the root, as shown in figure 7. There were no failures in the riveted connections between the cover and the bulkheads of beam 2.

Strengths of corner flanges.- By extrapolation of the load-stress curves from the load of 13.0 kips to the ultimate load of 14.1 kips, the stress in the formed corner-flange angles of beam 1, corrected to the centroid, was found to be 46.5 kips per square inch. The ultimate stress calculated by the shear-lag theory was 48.5 kips per square inch, or approximately 4 percent greater than the extrapolated stress. The extrapolated stress is 6 percent greater than the typical compressive yield stress of 44.0 kips per square inch given by reference 4.

For beam 2, when the load-stress curves were extrapolated from 19.0 kips to the ultimate of 22.1 kips, the stress corrected to the centroid of the extruded corner-flange angle was found to be 49.8 kips per square inch. The ultimate stress calculated by the shear-lag theory was 54.1 kips per square inch, or approximately 9 percent greater than the extrapolated stress. This discrepancy may be partly due to the assumption that the experimental stresses in the corner angles were equal to those measured in the adjoining sheet.

The extrapolated flange stress of 49.8 kips per square inch is 28 percent greater than the compressive yield stress of 38.8 kips per square inch shown in figure 2(b) and 21 percent less than the average ultimate compressive stress of 63.1 kips per square inch developed by the samples of the extruded corner-flange angle.

Strengths of cover sheets.- The bulkhead spacing at the root was 10 inches. If a length of 10 inches of the corrugated sheet were isolated from the box beam, the slenderness ratio would be 37.2 for pinned ends. The allowable column stress would be 43.5 kips per square inch (reference 5, fig. 5-5).

The average stresses in the covers at failure were 28.8 kips per square inch for beam 1 and 37.7 kips per square inch for beam 2. The failures in both beams, therefore, did not occur in the cover. This conclusion was confirmed by the observations made during the test that both failures were precipitated in the corner angles.

CONCLUSIONS

In tests on two aluminum-alloy box beams with corrugated covers, the measured stresses in the corner flanges at the root agreed with the stresses calculated by the shear-lag theory within 10 percent for the beam having corner-flange angles of formed sheet and within 5 percent for the beam having extruded corner-flange angles.

The formed corner-flange angles (spar caps), which were somewhat thicker than the cover sheet, developed a stress slightly greater than the compressive yield stress for the material.

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The extruded corner-flange angles, which were several
times as thick as the cover sheet, developed definitely

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Fig. 1

$2 \text{ } Ls \text{ } 1\frac{1}{4} \times 1\frac{1}{4} \times \frac{1}{4}$

(1) .0780 (2)

SYM. ₵

6.44

A=.083 A=.246 .0531

$L\frac{3}{4} \times \frac{3}{4} \times .064$

$L\frac{3}{4} \times \frac{3}{4} \times \frac{3}{16}$

16.5
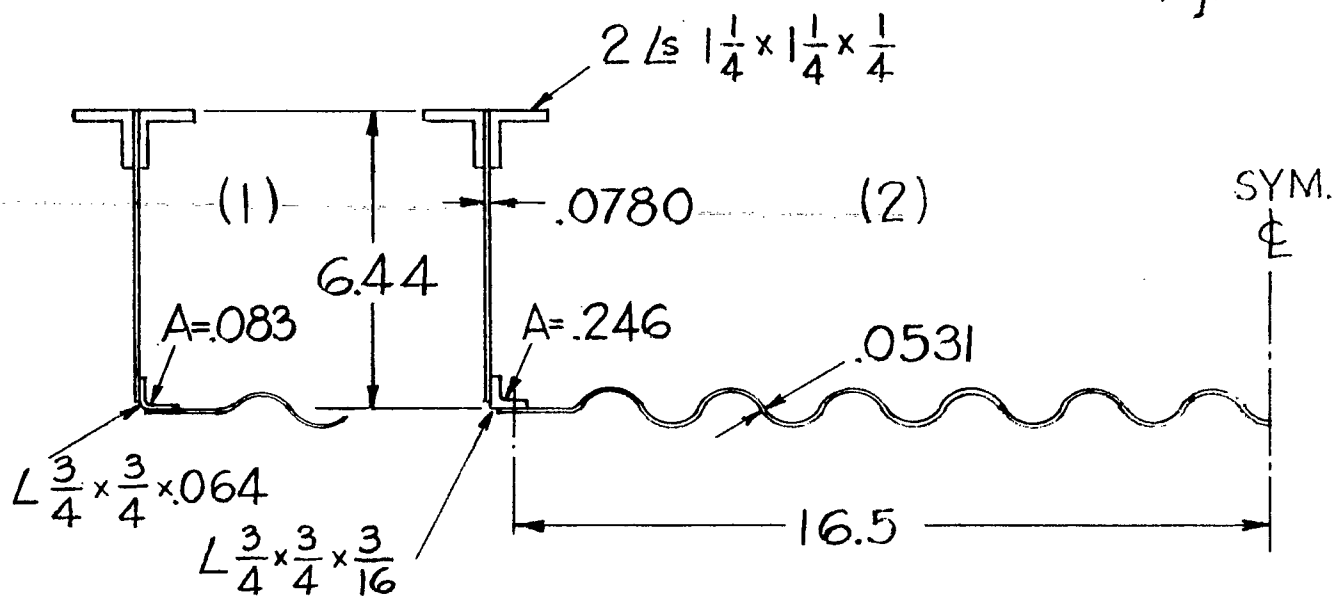
(a) Cross sections of beam 1 and beam 2.

Bulkheads

SYM. ₵

P   P   P   P

10

4@22=88
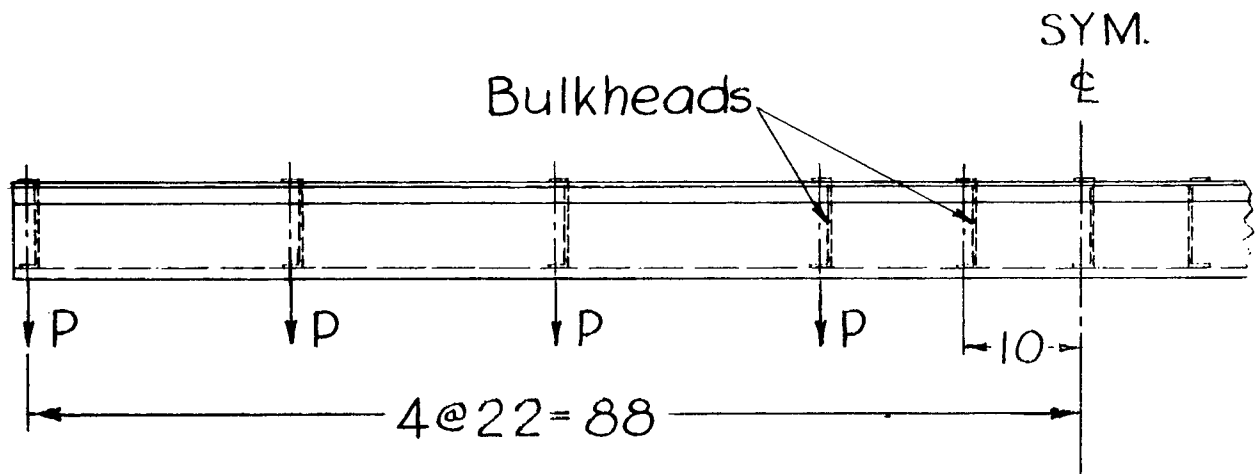
(b) Half span of beams 1 and 2 with distributed load.

Figure 1.–Dimensions of test beams.
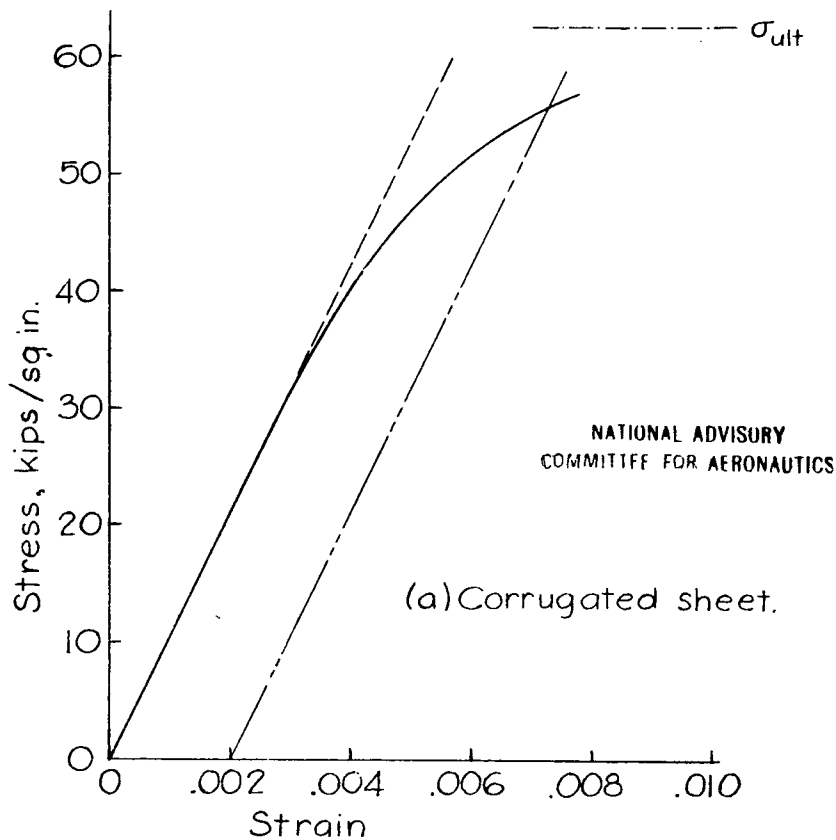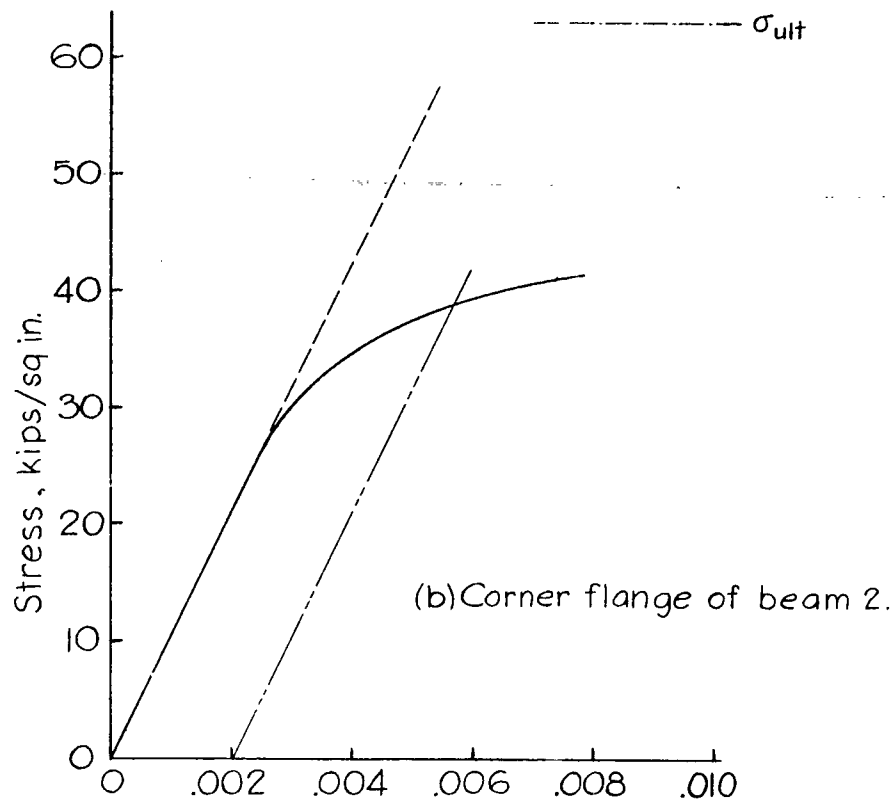
Figure 2.— Stress-strain curves for cover materials.

Strain gage
Centroid of cover
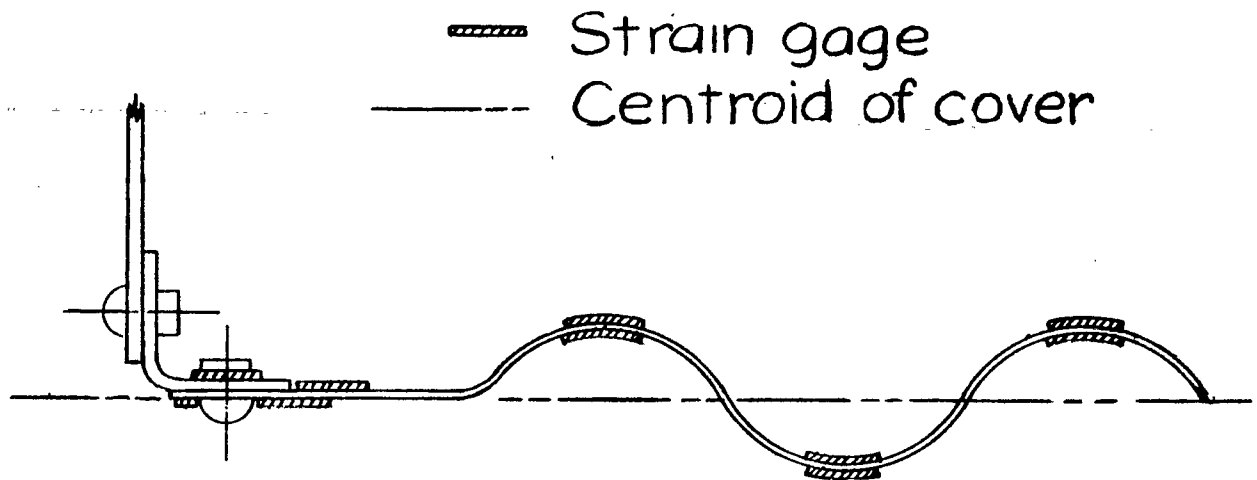
(a) Beam 1.
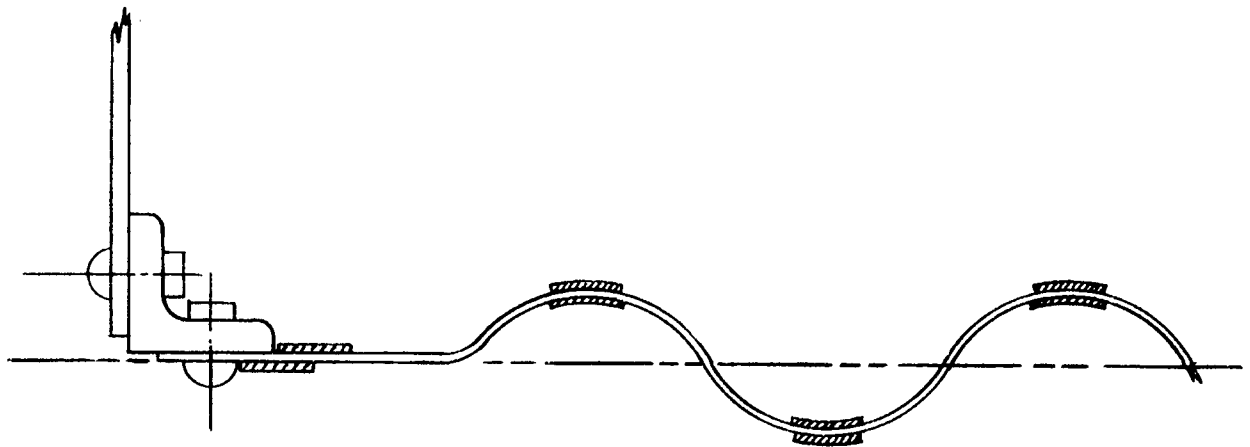
(b) Beam 2.

Figure 3.—Typical locations of electrical strain gages.
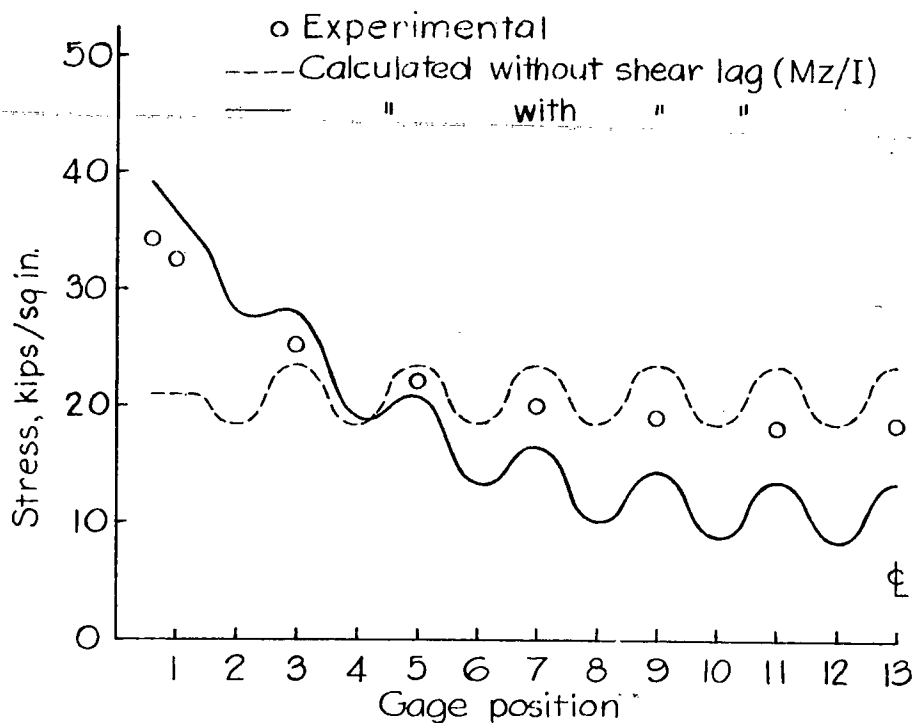
(a) Root station.
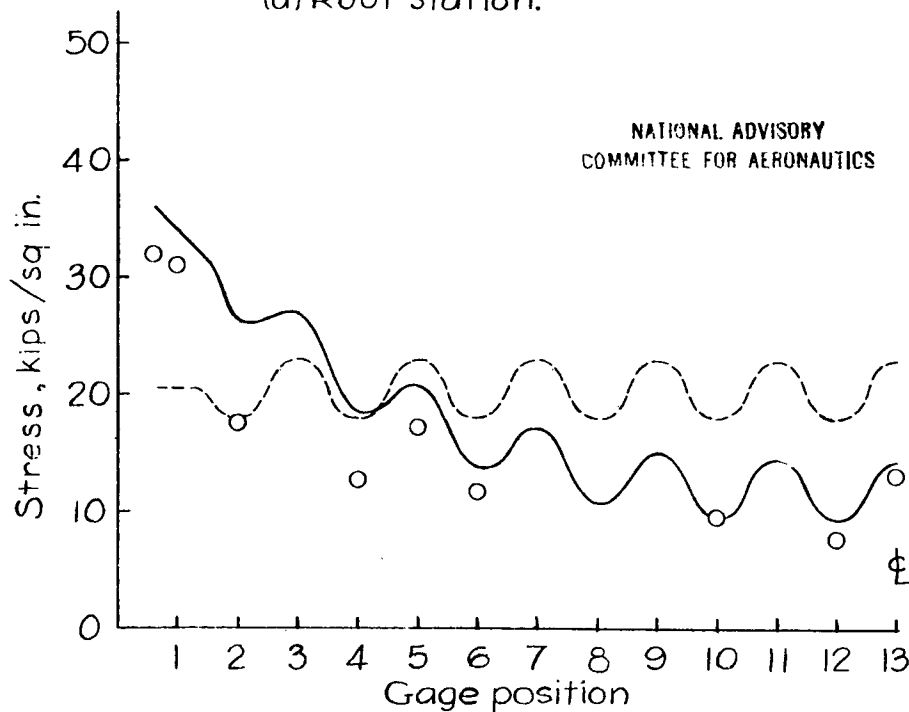
(b) Station $1\frac{1}{4}$ inches.

Figure 4.— Chordwise distribution of stresses in beam I with jack load of 11 kips.
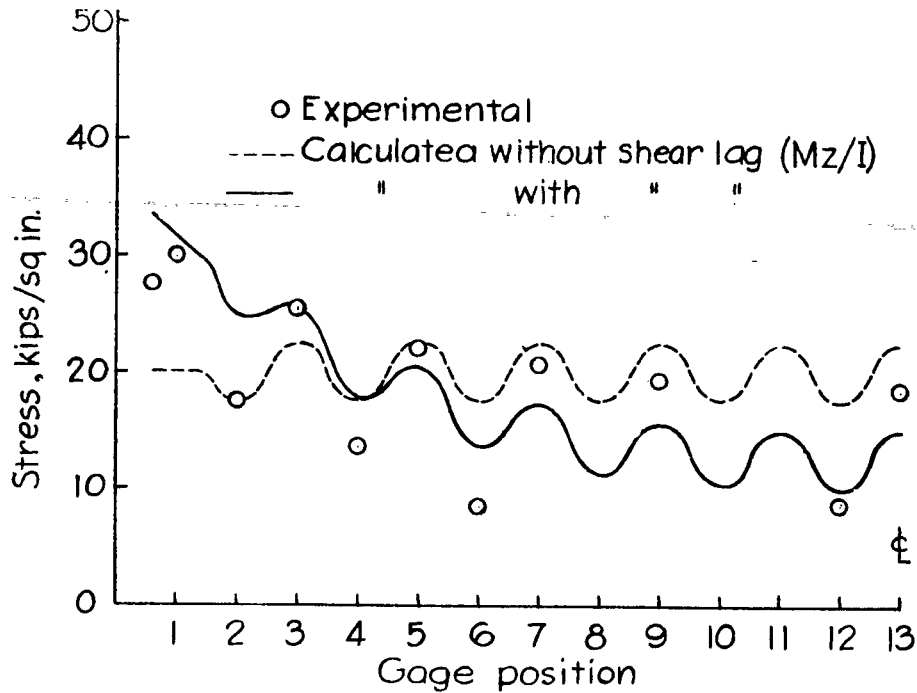
(c) Station $2\frac{1}{2}$ inches.

Figure 4.— Concluded.

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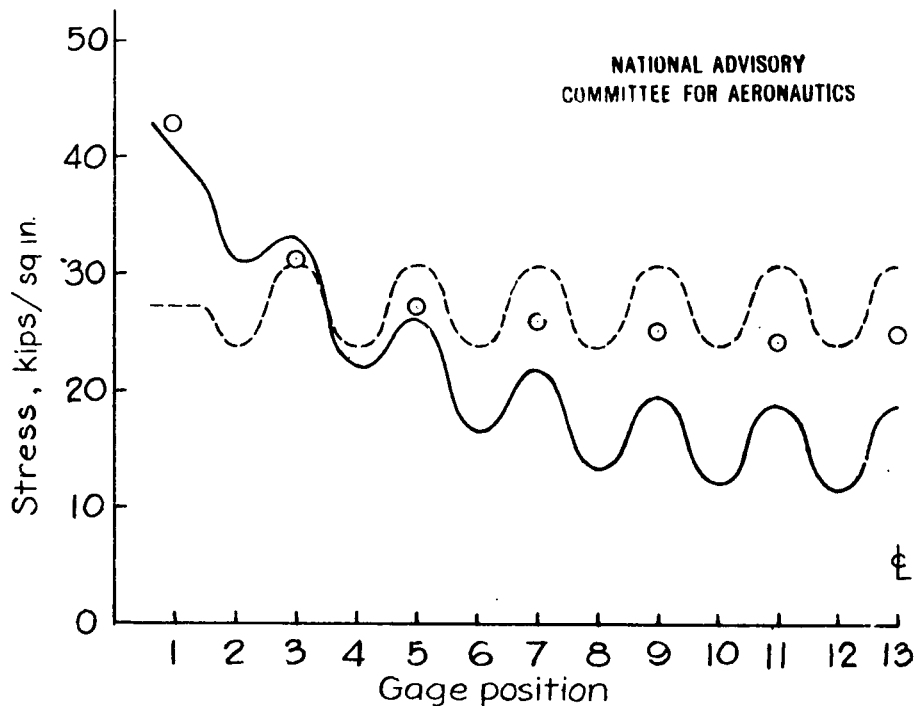
(a) Root station.

Figure 5.— Chordwise distribution of stresses
in beam 2 with jack load of 16 kips.
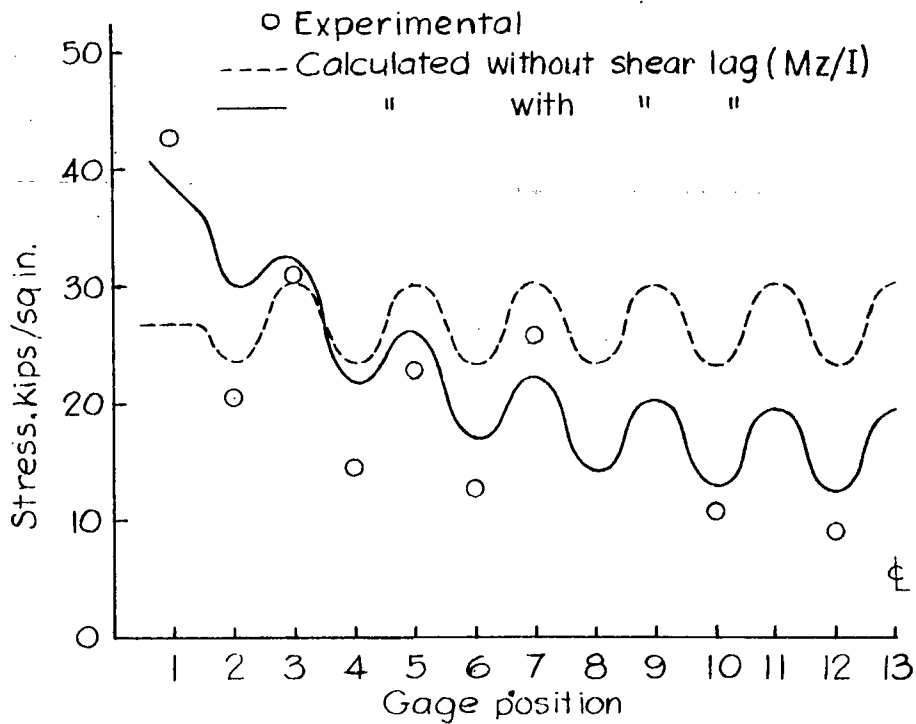
(b) Station $1\frac{1}{4}$ inches.
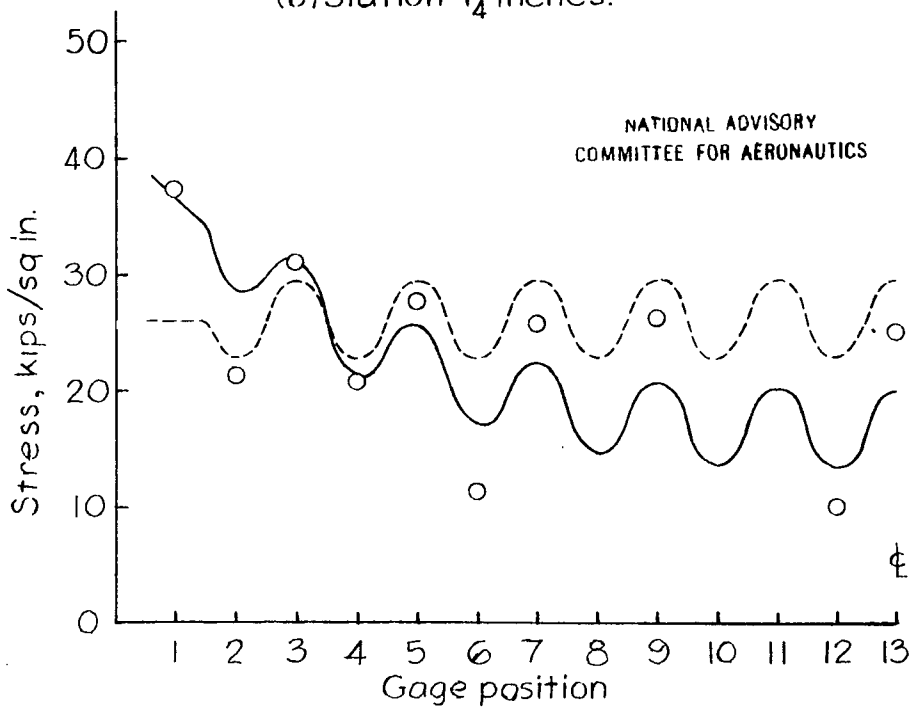
(c) Station $2\frac{1}{2}$ inches.

Figure 5 - Concluded.
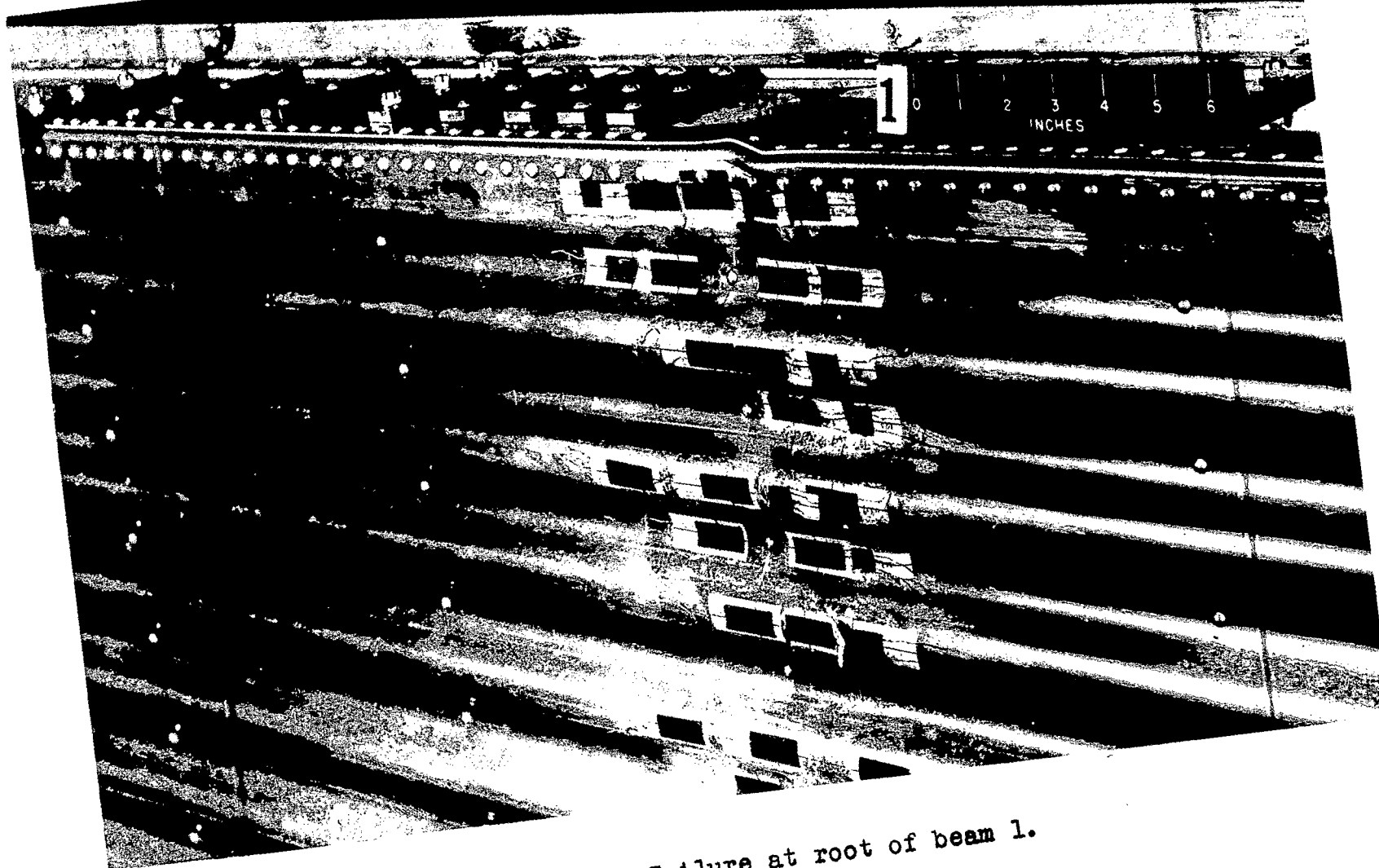
Figure 6.- Failure at root of beam 1.

Fig. 6
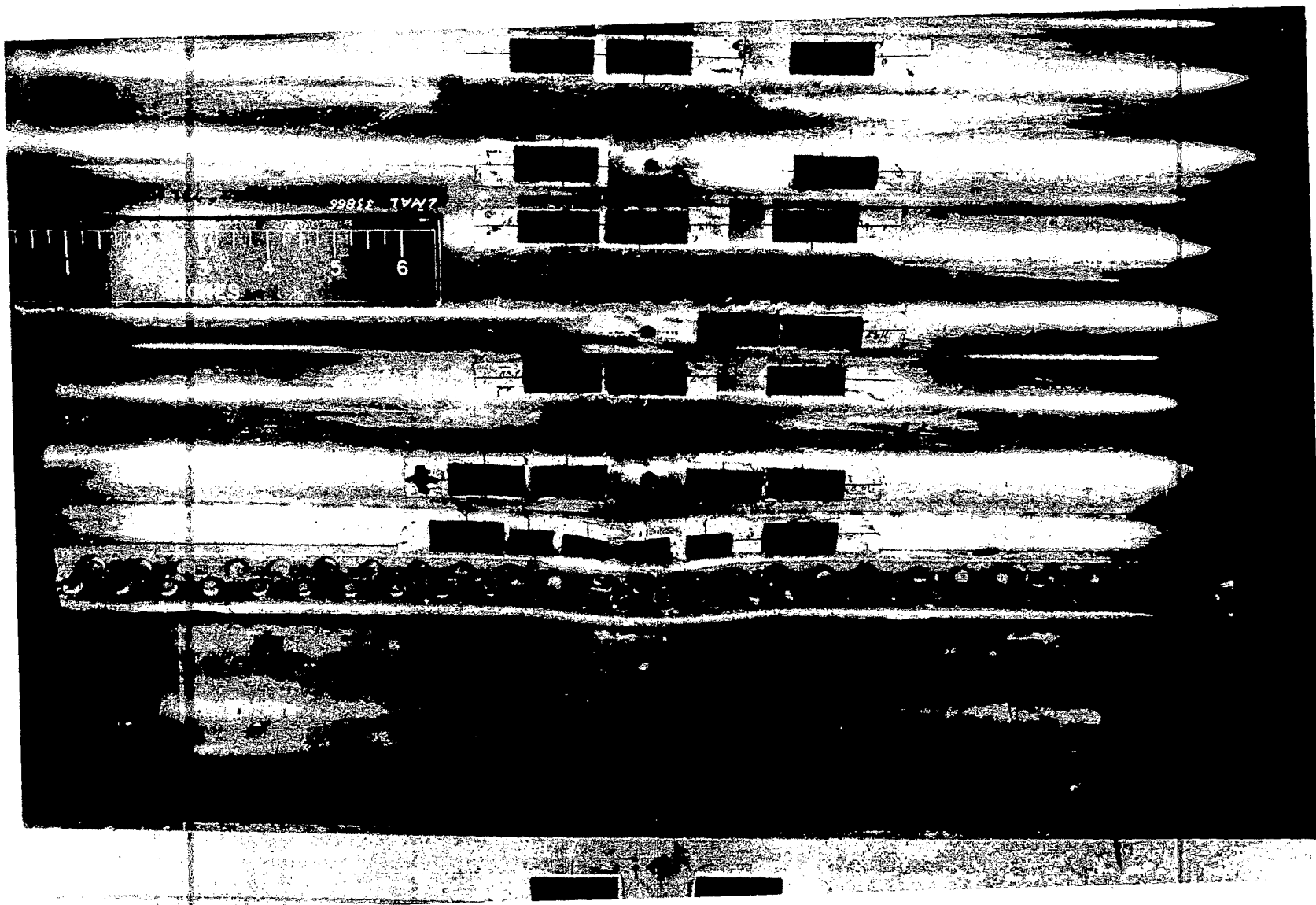
Figure 7.- Failure at root of beam 2. Bulkhead removed.

Fig. 7

ABSTRACT:

Strain measurements were made on compression side of box beams with corrugated
aluminum-alloy covers loaded to failure. Angles formed from sheet were used for
corner flanges in beam one, whereas extruded angles were used in beam two. By
use of shear-lag theory, stresses in corner flanges at root could be predicted to
approximately 10% for beam one and 5% for beam two. Failure in each beam occurred
in corner angle at a stress that was above compressive yield stress for material.

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